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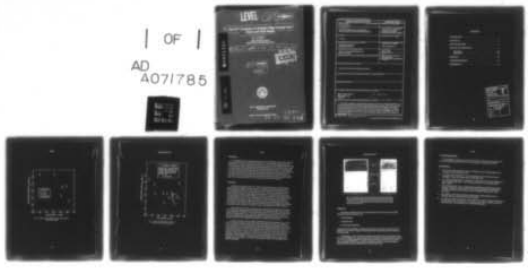

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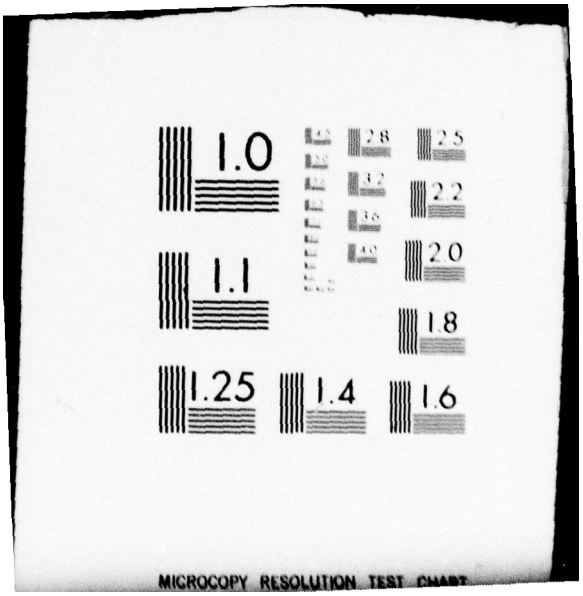
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NRL Report 8325

The SCC Properties of Modified High-Strength Steel Plates and Weld Metals.

C. T. Fujii

Metals Performance Branch
Material Science and Technology Division

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This report describes the results of baseline studies on the effects of chemical, metallurgical, and mechanical factors on the SCC properties of high-strength steels and weldments. The primary materials were quench-and-tempered steels or weld metals in the HY-100 and HY-130 systems with complex martensitic microstructures. The cantilever beam method was used to measure K_{Iscc} of the materials in 3.5% sodium chloride (NaCl) solution under zinc-coupled conditions. This parameter was utilized to rank the materials and to evaluate the effects of processing, welding procedure, and tempering on SCC properties.

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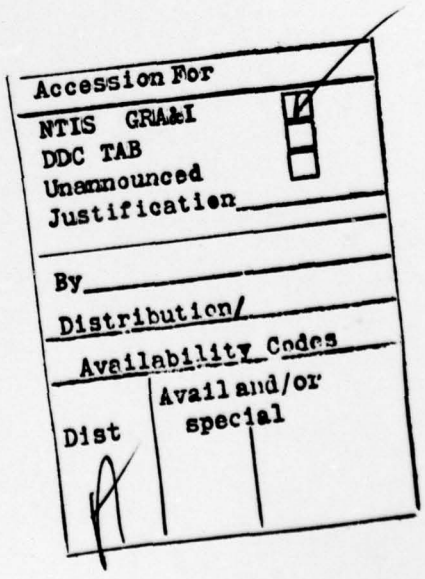


THE SCC PROPERTIES OF MODIFIED HIGH-STRENGTH STEEL PLATES AND WELD METALS

BACKGROUND

Stress-corrosion cracking (SCC) is a problem which is likely to occur with greater frequency as the use of higher strength materials increases to meet the growing performance requirements of modern structures. Naval structures are especially vulnerable because they are constantly exposed to a particularly aggressive environment which provides conditions favorable to corrosion-cracking damage. Such structures are usually fabricated by welding, and weldments are widely recognized as potential weak links in engineering structures. There is substantial evidence that, for most high-strength steels, weldments are more susceptible to SCC than the corresponding base plates [1,2].

In view of the potentially serious limitation imposed by weldments on the structural performance of high-strength steel systems in marine environments, a Navy study focused on weld-metal improvement was initiated in FY-1977. This study—the High-Strength Steel Weldment Subcritical Cracking Program—is sponsored by the Naval Sea Systems Command (SEA 035) and managed by the Ship Materials Engineering Department of the David W. Taylor Naval Ship Research and Development Center, Code 28, Annapolis, Maryland. The major objective has been to determine the effects of compositional, metallurgical, and microstructural changes induced by processing, welding, or heat treating on SCC properties to attempt to identify promising paths for weld metal improvements. Both base plates and weld metals in the 800- to 1400-MPa (110- to 200-ksi) yield strength range were included in the baseline studies.

The baseline SCC characterization studies were conducted by the Naval Research Laboratory under Task 1.4 in the program cited above. An earlier report described the progress made in FY-1977 [3]. This report summarizes the SCC test results obtained in FY-1978 (Oct. 1, 1977-Sept. 30, 1978).

MATERIALS

The materials characterized in these studies included (a) HY-130 and HY-100 base plates in the as-received and heat-treated conditions, (b) four different weld metal compositions in the HY-130 system, and (c) an HY-100 weld metal. The gas-metal-arc (GMA) and gas-tungsten-arc (GTA) welding processes were used to prepare most of the weldments. The exceptions were two HY-130 weldments which were fabricated by the shielded-metal-arc (SMA) process. Details of the welding procedures and heat treatments may be found in Refs. 3 and 4.

Manuscript submitted April 30, 1979.

The tensile properties and chemical composition of the base metals are summarized in Tables 1 and 2, and that of the weld metals in Tables 3 and 4.

TEST PROCEDURES

Single-edge-notched (SEN) bend specimens were used to evaluate the SCC properties of the materials. All specimens were side-grooved and fatigue-precracked. The base plate SCC specimens were 25 mm (1 in.) thick, the full thickness of the as-rolled plate, with the crack-plane perpendicular to the width or long transverse (T) and parallel to the rolling or longitudinal (L) directions (TL orientation). The as-fabricated weldments were all 38 mm (1.5 in.) thick, and SCC specimens from weldments prepared in FY-1977 were initially tested in full thickness. These earlier welds were retested together with all new weldments prepared in FY-1978 after reducing the SEN specimen thickness to 25 mm (1 in.) by removal of the outermost material from opposing faces of the specimen, as illustrated in Fig. 1.

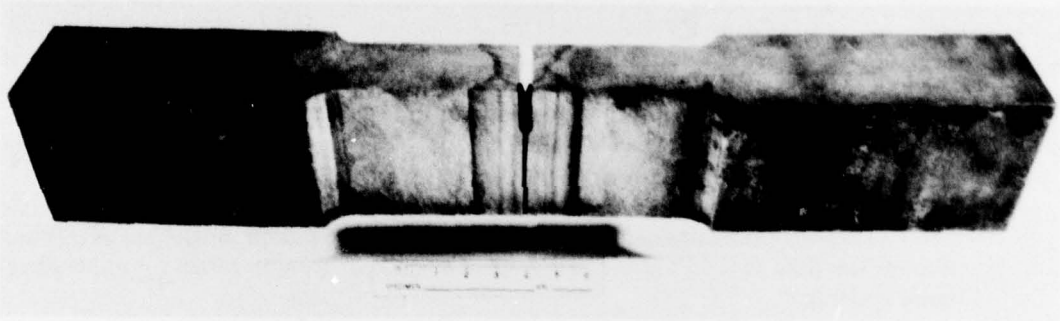


Fig. 1 — The reduced-section weld-metal specimen for K_{Iscc} determination

The cantilever test method was used to determine the threshold stress-intensity factor (K_{Iscc}) for stress-corrosion cracking [5]. The essential features of this test method are illustrated in Fig. 2. The method is characterized by a constant load (P) but an increasing K_I as the crack grows by stress corrosion, as illustrated in the graphs. The symbols a_i and a_f are initial and final crack lengths; P_i and P_f are initial and final loads. The Kies' equation shown in Fig. 2, where M is the moment and a, B, and W are the crack length, thickness, and width, respectively, was used to calculate all of the stress-intensity factors, K_I [6];

For a new material, the stress-intensity factor for fast fracture in air, K_{Ix}, was first measured and subsequently used to guide the initial load setting for the first K_{Iscc} test. The initial load for the first K_{Iscc} test was usually 40 to 50% of that corresponding to K_{Ix}. For a material that was being retested, the K_{Iscc} value determined previously was used as a point of reference for the retest. The initial load in the retest corresponded to a K value that was 11-22 MPa$\sqrt{\text{m}}$ (10-20 ksi$\sqrt{\text{in.}}$) below this reference point. To determine the critical K_I value for initiating SCC, a step-loading bracketing technique was used. Loads were increased

Table 1 — Tensile Properties of Base Metals
(Data from David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory, Code 2821)

Material*	Condition	Code	Yield Strength, 0.2% Offset		Ultimate Tensile Strength		Elongation (%)	Red'n in Area (%)
			(MPa)	(ksi)	(MPa)	(ksi)		
HY-130 (EF)	As received	A	938	136	979	142	21	55
HY-130 (EF/TE)	Heat treated	C	910	132	965	140	16	57
HY-130 (EF/CG)	Heat treated	H	1027	149	1103	160	19	63
HY-130 (H/RT)	Heat treated	I	917	133	979	142	21	61
HY-130 (ESR)	As received	B	986	143	1007	146	19	61
HY-100 (EF)	As received	J	593	86	689	100	28	72
HY-100 (EF)	Heat treated	K	814	118	876	127	20	64

*EF — electric furnace
TE — temper embrittled
CG — coarse grain
H/RT — Code H retempered
ESR — electroslag remelt

Table 2 — Chemical Composition of Base Metals
(Data from David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory, Code 2821)

Material*	Code	Chemical Analysis (wt %)											
		C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	N	O
HY-130/EF	A,C,H,I	0.11	0.76	0.005	0.004	0.31	0.022	5.00	0.42	0.53	0.043	0.011	0.0032
HY-130/ESR	B	0.10	0.80	0.006	0.005	0.14	0.120	5.09	0.46	0.51	0.062	0.010	0.0012
HY-100	J,K	0.16	0.24	0.004	0.015	0.13	0.150	2.55	1.27	0.28	0.007	0.006	0.0023

*EF — electric furnace
ESR — electroslag remelt

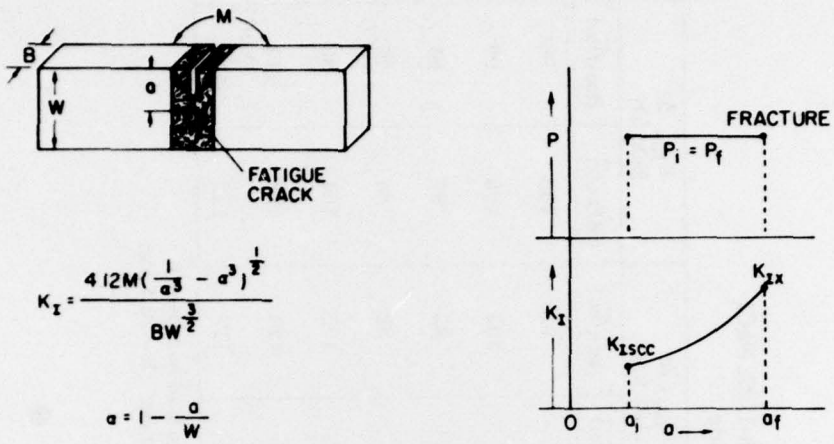
Table 3 — Tensile Properties of Deposited Weld Metals
(Data from David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory, Code 2821)

Electrode/ Process*	Condition	Code	Yield Strength 0.2% Offset		Ultimate Tensile Strength		Elongation (%)	Red'n in Area (%)
			(MPa)	(ksi)	(MPa)	(ksi)		
140S/GMA	As welded	C	869	126	965	140	22	70
140S/GMA	As welded	D	993	144	1055	153	19	68
140S/GTA	As welded	F	1041	151	1048	152	25	78
140S/GMA	Heat treated	L	1000	145	1062	154	17	36
AX140/GMA	As welded	R	1034	150	1096	159	17	64
AX140/GTA	As welded	S	1041	151	1055	153	22	72
AX140/GMA	As welded	U	958	139	1082	157	17	65
AX140/GMA	As welded	W	1007	146	1069	155	17	60
AX140/GTA	As welded	AB	1000	145	1048	152	20	68
HY-130/GMA	As welded	G	938	136	993	144	16	52
HY-130/GMA	Heat treated	K	903	131	958	139	11	21
HY-130/GTA	As welded	T	1048	152	1048	152	25	78
HY-130/GMA	As welded	V	972	141	1014	147	14	55
14018/SMA	As welded	E	993	144	1034	150	18	66
14018/SMA	As welded	X	1020	148	1055	153	16	64
120S/GMA	As welded	A	820	119	883	128	21	70
120S/GMA	As welded	B	862	125	896	130	20	69
120S/GTA	As welded	Z	931	135	931	135	25	75

*GMA — gas metal arc
GTA — gas tungsten arc
SMA — shielded metal arc

Table 4 — Chemical Composition of Deposited Weld Metals
(Data from David W. Taylor Naval Ship Research and Development Center, Annapolis Laboratory, Code 2821)

Electrode/ Process	Code	Chemical Analysis (wt %)											
		C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	N	O
140S/GMA	C,D,L	0.11	1.32	0.004	0.003	0.32	0.039	2.81	0.60	0.84	0.010	0.006	0.0167
140S/GTA	F	0.13	1.43	0.004	0.003	0.35	0.037	2.97	0.67	0.83	0.011	0.006	0.0010
AX140/GMA	R	0.093	1.50	0.009	0.007	0.31	0.057	2.59	0.91	0.61	0.016	0.006	0.0205
AX140/GMA	AB	0.10	1.77	0.006	0.005	0.36	0.064	2.56	0.98	0.60	0.021	0.008	0.0024
AX140/GTA	S	0.11	1.47	0.007	0.005	0.33	0.047	2.78	0.82	0.60	0.030	0.007	0.0017
HY-130/GMA	G,K	0.083	0.69	0.006	0.002	0.23	0.17	4.99	0.56	0.49	0.063	0.012	0.0400
HY-130/GTA	T	0.077	0.78	0.005	0.001	0.25	0.13	4.88	0.56	0.48	0.059	0.007	0.0012
14018/SMA	E	0.064	1.16	0.009	0.003	0.45	0.02	3.80	0.58	0.85	0.019	0.011	0.0266
14018/SMA	X	0.067	1.17	0.007	0.004	0.55	0.035	3.74	0.62	0.83	0.016	0.008	0.0295
120S/GMA	A,B	0.10	0.96	0.004	0.008	0.23	0.160	2.50	0.45	0.43	0.008	0.009	0.0201
120S/GTA	Z	0.11	1.54	0.005	0.009	0.35	0.190	2.48	0.37	0.46	0.005	0.008	0.0020



$$K_I = \frac{4.12M\left(\frac{1}{a^3} - a^3\right)^{\frac{1}{2}}}{BW^{\frac{3}{2}}}$$

$$a = 1 - \frac{a}{W}$$

Fig. 2 — Essential features of the cantilever test method, the SEN specimen, and the Kies' equation for calculating the stress-intensity factor, K_I

incrementally every 500 h until crack growth was indicated by a precision dial gage positioned near the loaded end of the cantilever beam to monitor its movement. Each step or load increment corresponded to an increase in K of approximately 11 MPa$\sqrt{m}$ (10 ksi$\sqrt{in.}$). Upon completion of each SCC test, stress-corrosion crack growth was verified by visual and microscopic examination of the fracture surfaces. The SCC threshold was considered to be bracketed between the K_I which initiated crack growth and the highest K_I which failed to do so within 500 hours. Thus, K_{Iscc} was obtained by averaging the K_I values associated with the final two loads.

All of the SCC tests were conducted in nonflowing 3.5-percent sodium chloride (NaCl) solution with the specimens coupled to zinc anodes and at ambient temperature of approximately 25°C. The salt solution was changed each work day.

RESULTS AND DISCUSSION

The results of the cantilever SCC tests are given in Table 5 for the base metals and in Table 6 for the weld metals. Included in the tables are K_{Ix} values—the stress-intensity factors for fast fracture in air—and K_{Iscc} values for experiments conducted with two different hold times between load increments—100 h in one set of tests and 500 h in the other. The longer hold times were utilized in the retests to increase the reliability of the K_{Iscc} data base. The K_{Iscc} values from the 500-h tests are plotted versus the yield strength in Fig. 3 for the base metals and in Fig. 4 for the weld metals to assist in evaluating SCC behavioral trends and identifying the exceptional SCC performers.

Table 5 — SCC Properties of the Base Metals in Quiescent 3-1/2% NaCl Solution with the Specimen Coupled to Zinc Anode

Material*	Code	Condition	Yield Strength		K_{Ix}, air		K_{Iscc}, Zn (100 h)†		K_{Iscc}, Zn (500 h)†	
			(MPa)	(ksi)	(MPa$\sqrt{m}$)	(ksi$\sqrt{in.}$)	(MPa$\sqrt{m}$)	(ksi$\sqrt{in.}$)	(MPa$\sqrt{m}$)	(ksi$\sqrt{in.}$)
HY-130 (EF)	A	As received	938	136	190	173	101	92	105	96
HY-130 (ESR)	B	As received	986	143	176	160	112	102	105	96
HY-130 (EF/TE)	C	Heat treated	910	132	158	144	97	88	92	84
HY-130 (EF/CG)	H	Heat treated	1027	149	187	170	90	82	84	76
HY-130 (H/RT)	I	Heat treated	917	133	195	177	110	100	104	95
HY-100 (EF)	J	As received	593	86	148	135	132	120	123	112
HY-100 (EF)	K	Heat treated	814	118	193	176	129	117	122	111

*EF — electric furnace
ESR — electroslag remelt
TE — temper embrittled
CG — coarse grain
H/RT — code H retempered

†Hold times between load increments
All specimen thickness: B = 25.4 mm

Table 6 — SCC Properties of the Weld Metals in Quiescent 3-1/2% NaCl Solution with the Specimen Coupled to Zinc Anode

Base Plate / Electrode	Weld†	Code	Condition	Yield Strength (MPa)	Yield Strength (ksi)	K_{Ix}, air (MPa$\sqrt{m}$)	K_{Ix}, air (ksi$\sqrt{in.}$)	K_{Iscc}, Zn (100 h)‡ (MPa$\sqrt{m}$)	K_{Iscc}, Zn (100 h)‡ (ksi$\sqrt{in.}$)	K_{Iscc}, Zn (500 h)‡ (MPa$\sqrt{m}$)	K_{Iscc}, Zn (500 h)‡ (ksi$\sqrt{in.}$)
HY-130 / 140S	GMA	C	As welded	869	126	184	167	[91]	[83]	102	93
	GMA	D	As welded	993	144	209	190	[90]	[82]	95	86
	GMA	L	Heat treated	1041	151	56	51	[42]	[38]	—	—
	GTA	F	As welded	1000	145	244	222	113	103	99	90
HY-130 / AX140	GMA	R	As welded	1034	150	154	140	[109]	[99]	99	90
	GTA	S	As welded	1041	151	201	183	[108]	[98]	97	88
	GMA	U	As welded	958	139	191	174	119	108	102	93
	GMA	W	As welded	1007	146	159	145	100	91	90	82
	GTA	AB	As welded	1000	145	213	194	102	93	<102	<93
HY-130 / M Comp.*	GMA	G	As welded	938	136	135	123	[101]	[92]	88	80
	GMA	K	Heat treated	903	131	153	139	[123]	[112]	—	—
	GTA	T	As welded	1048	152	226	206	[126]	[115]	119	108
	GMA	V	As welded	972	141	127	116	119	108	96	87
HY-130 / 14018	SMA	E	As welded	993	144	154	140	[110]	[100]	103	94
	SMA	X	As welded	1020	148	167	152	88	80	88	80
HY-100 / 120S	GMA	A	As welded	820	119	201	183	122	111	123	112
	GMA	B	As welded	862	125	197	179	122	111	116	106
	GTA	Z	As welded	931	135	220	200	110	100	102	93

*M Comp. — Matching composition
†GMA — gas metal arc
GTA — gas tungsten arc
SMA — shielded metal arc

‡Hold times between load increments
For K_{Iscc} in brackets: B = 37.6 mm (1.5 in.)
Other K_{Iscc} specimens: B = 25.4 mm (1.0 in.)
(B is specimen thickness)

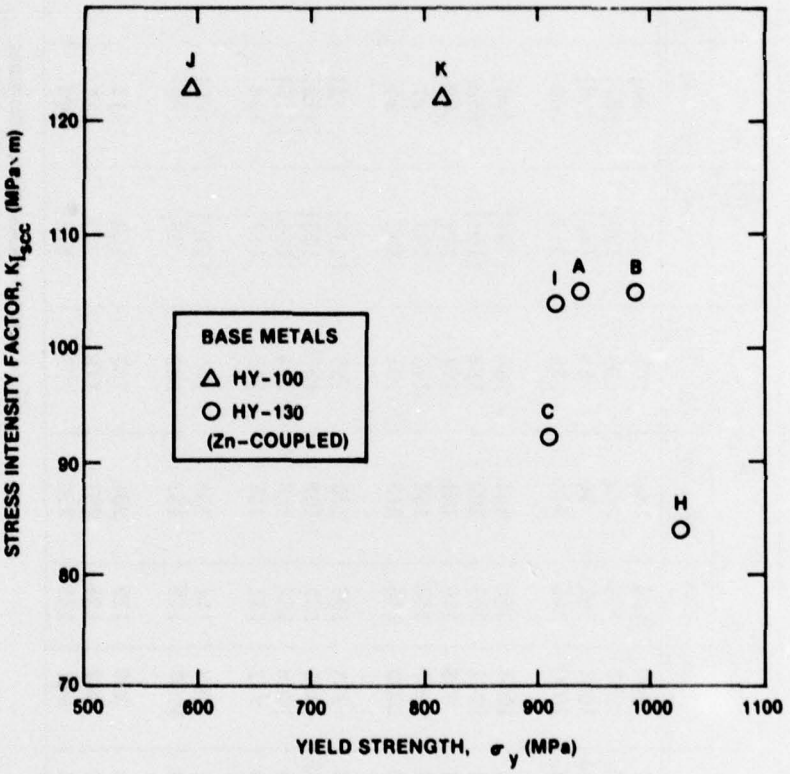


Fig. 3 — Effect of yield strength on $K_{I_{scc}}$ of HY-100 and HY-130 base metals

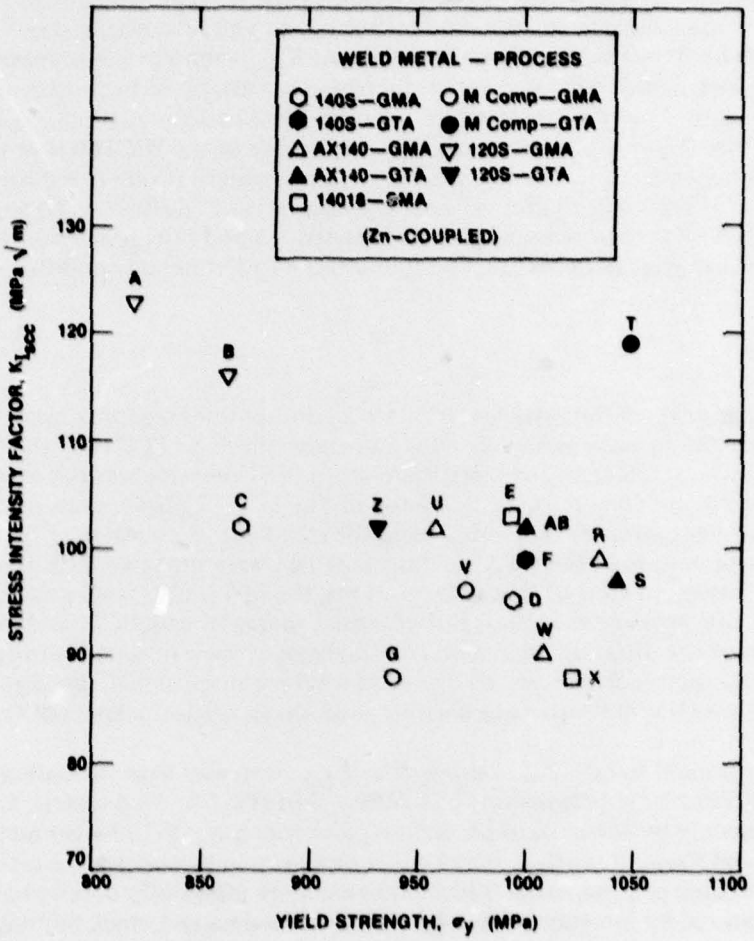


Fig. 4 — Effect of yield strength on K_{Iscc} of HY-100 and HY-130 weld metals

Base Metals

As indicated in Fig. 3, the SCC properties of the HY-100 base metals (Codes J and K) appear to be insensitive in the 600-800 MPa range to yield-strength changes induced by heat treatment. There is a significant lowering in K_{Iscc} values in the transition from HY-100 to HY-130 base metals and an apparent increased sensitivity to heat treatment and changes in yield strength. Heat treatment which produced embrittlement (Code C) or coarse-grain microstructure (Code H) decreased the SCC resistance of the HY-130 base metal. Retempering Code H material which produced a lower yield strength (Code I) improved the SCC properties of HY-130. Both as-received electroslag remelt (ESR/Code B) and electric furnace (EF/Code A) processed materials had relatively good SCC resistance with little difference in SCC behavior between the two under these experimental conditions.

Weld Metals

The first year baseline studies (FY—1977) on full-thickness weld metal specimens revealed that the surfaces were generally more susceptible to SCC than the midportion of the weldments. Evidence for this difference in SCC behavior was the shape of the advancing stress-corrosion crack, as illustrated in Fig. 5a. The effect, presumed to be the result of different levels of tempering from the middle to the surface of the weld metal, was most pronounced in the GTA weldments which were prepared with the largest number of welding passes. In view of these observations, the 500-h SCC tests were conducted on reduced-section specimens to limit this potential source of variability and to permit a comparison of the different weldments on the basis of their optimum properties. Figure 5b, a fracture surface from a reduced-section weld-metal specimen, displays a fairly straight crack front which is indicative of relatively uniform through-thickness SCC properties.

As for general trends, Fig. 4 shows that K_{Iscc} decreases with increasing yield strength from a high value of approximately 120 MPa$\sqrt{m}$ of HY-100 weld metals, Codes A and B, to approximately 90 MPa$\sqrt{m}$ of the higher yield strength HY-130 weld metals. The major effect of yield strength on K_{Iscc} may be due primarily to mechanical factors associated with the cracking process, crack initiation being more effectively deterred in lower yield strength material by increasing crack-tip plastic zone sizes and crack blunting.

A notable exception to the generally observed effect of yield strength on K_{Iscc} is the Code T weldment produced by the GTA process with a filler wire that closely matched the composition of the HY-130 base plate. The outstanding SCC properties of the Code-T weld metal appears to be derived from a favorable weld-metal chemistry and microstructure. In particular, the Code-T weld metal is characterized by relatively low sulfur, oxygen, nitrogen, and manganese contents, and a fine-grain, tempered, martensitic microstructure. In contrast to this, the K_{Iscc} value of the 120S weld metal (Code Z) with higher sulfur and manganese contents is significantly lower in spite of its fabrication by the GTA process and a lower yield strength. It would thus appear that the negative effects of high yield strength on K_{Iscc} have been overridden by the favorable chemistry and metallurgy of the Code-T weld metal.

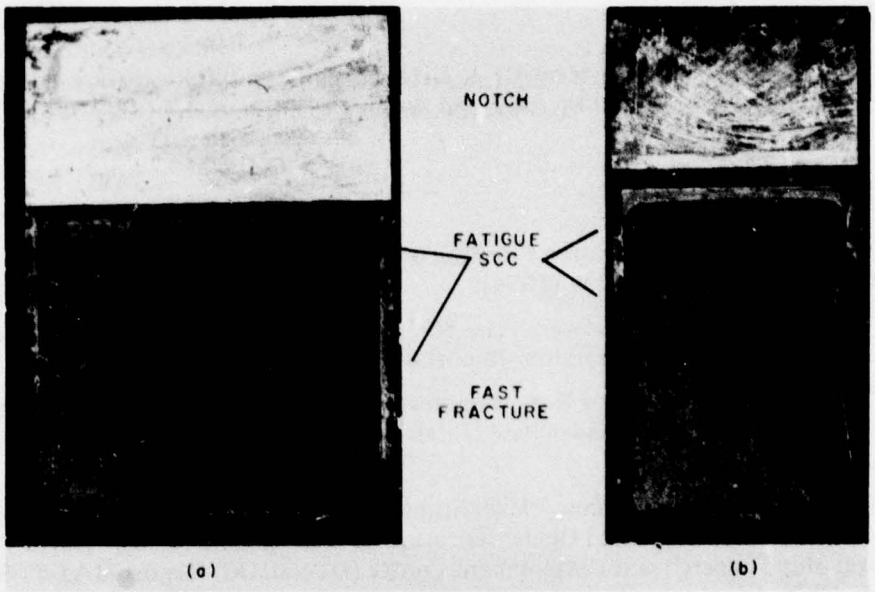


Fig. 5 — (a) Fracture surface of a full-thickness (38 mm) weld metal specimen (Code T) showing large differences in SCC propensity from the center of weld metal to the outer surfaces, and (b) fracture surface of a reduced-section (25 mm) weld metal specimen (Code T) showing a relatively straight stress-corrosion crack front

SUMMARY

The present studies have shown correlations between the SCC properties of high-strength steels and weld metals, and

- Yield strength
- Microstructure
- Weld metal composition

In general, low yield strength, a tempered martensitic microstructure, and low levels of impurities such as sulfur, oxygen, and nitrogen appear to favor improved SCC properties for these metals.

In utilizing K_{Iscc} data, it should be recalled that the SCC tests were conducted under zinc-coupled conditions in a quiescent salt water environment which polarized the specimen at -1.0 V as measured against the Ag/AgCl reference electrode. Implicit in this caveat is that the measured value of K_{Iscc} is unique to these test conditions, and that changes in electrochemical potential or environment will likely affect K_{Iscc}.

ACKNOWLEDGMENTS

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REFERENCES

1. T.G. Gooch, "Stress Corrosion Cracking of Welded Joints in High Strength Steels," Welding Journal 53:287-298 (1974).
2. C.T. Fujii and E.A. Metzbower, "The SCC Properties of HY-130 Steel Plate and Weldments," NRL Memorandum Report 3463, Mar. 1977.
3. C.T. Fujii, F.W. Fraser, and E.A. Metzbower, "Stress-Corrosion Cracking Characterization of High-Strength Steels — Base Metals and Weldments," NRL Report 8230, May 12, 1978.
4. P.W. Holsberg and E.C. Dunn, "High-Strength Steel Weldment Subcritical Cracking Program — Preparation and Characterization of Base Line Materials," David Taylor Naval Ship Research and Development Center (DTNSRDC) Report MAT-77-95, Feb. 1978.
5. B.F. Brown, "A New Stress-Corrosion Cracking Test for High Strength Alloys," Materials Research and Standards 6:129-133 (1966).
6. J.A. Kies, H.L. Smith, H.E. Romine, and H. Bernstein, "Fracture Testing of Weldments," pp. 328-356 in *Fracture Toughness Testing and Its Application*, American Society for Testing and Materials, Philadelphia, Pa. ASTM STP 381 (1965).